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# PHET: AN INTERACTIVE SIMULATION TECHNOLOGY FOR LEARNING OUTCOMES BASED TEACHING-LEARNING SCIENCE

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## ABSTRACT

Recognizing the immense potential of Information and Communication Technology (ICT) as an essential part of the teaching-learning process for enhancing connectivity, content, capacity, and collaboration among various stakeholders, the National Education Policy 2020 advocates for education to reach individual learners through both online and offline modes of delivery. NEP-2020 further states that virtual laboratories provide equal access to quality practical and hands-on experiment-based learning experiences for all students. It also emphasizes that the teaching-learning process through games and simulations positively affects the quality of education. Traditionally, these methods have been associated with strong teachers who maintain high degrees of personal contact with learners. They can be utilized by students individually, in groups, or through virtually demonstrated experiments to conduct the required activities. In this area, PhET simulations offer dynamic access to multiple representations, making the invisible visible, scaffolding inquiry, and allowing for safe and quick access to multiple entry points while being engaging and fun for both teachers and students. PhET Interactive Simulations is an online and offline platform developed by the University of Colorado Boulder, featuring more than 159 interactive simulations (56 in Physics, 30 in Chemistry, 48 in Mathematics, 18 in Earth Science, and 7 in Biology) for teaching and learning science from elementary to higher levels. These simulations enable students to conduct experiments more flexibly and interactively using text, video, multimedia, animation, and simulations. They also aid in hands-on, activity-based skill training. This paper focuses on the application of PhET simulations in science education within the current context of digital education. It also examines the status of laboratories in India, the use of PhET simulations for science (Physics, Chemistry, and Biology), the steps involved in accessing and using PhET simulations, the importance of their design and procedures, and their implications for enhancing practical abilities, skills, and assessment.

**KEYWORDS:** PhET Simulation, NEP-2020, Interactive Simulation, Physics Simulation, Biology Simulation, Chemistry Simulation

## INTRODUCTION

Science, as a discipline, involves the systematic study of the structure and behaviour of the physical and natural world through observation, experimentation, and the formulation of testable hypotheses, explanations, and predictions. High-quality science education is crucial for enhancing the overall quality of human life. It serves as a catalyst for economic growth and sustainable development across all sectors, engaging students in learning and fostering discipline through practical activities and analysis of environmental and health-related issues. The effectiveness of teaching and learning science relies on teachers, learners, and the methods of instruction in diverse educational settings. Factors such as the availability of resources, quality of textbooks, appropriateness of assessment systems, availability of laboratories and scientific equipment, the school environment, and the quality of science teachers significantly impact science education.

In May 1964, the Planning Commission established a panel on Science Education in Secondary Schools, chaired by Prof. M.S. Thacker. The panel developed standard lists of equipment for science laboratories and suggested grants for their provision. The Commission recommended that the equipment lists for physics, chemistry, and biology laboratories in high schools be based on the syllabi of the Maharashtra and U.P. Boards, with necessary modifications to meet syllabus requirements. Essential apparatus and equipment were to be supplied immediately when science is introduced in class IX. The Boards of Secondary Education should implement a system for evaluating students' practical laboratory work, encouraging students to make simple scientific instruments themselves to provide a practical basis for learning science at the secondary stage. The Kothari Commission (1964-66) emphasized the need to enhance school laboratories, focusing on locating problems, developing hypotheses, and designing procedures and experiments related to theory. It recommended significantly increasing expenditure on laboratories. Schools should have laboratory-cum-lecture rooms to store specimens, models, and charts with the necessary facilities, and advanced study courses should be available for talented students. Demonstration experiments and laboratory investigations should reflect the agricultural and industrial interests of the local community, making science teaching more realistic, interesting, and useful. Special laboratory work should teach the practical properties and peculiarities of materials, and schools should share costly equipment to minimize costs and enhance teaching-learning contributions. Well-planned visits to laboratories, museums, and other places should be arranged. The National Curriculum Framework (NCF) 2005

addressed issues in the teaching-learning environment to improve the education system. It highlighted that the absence of appropriate laboratory facilities drastically narrows subject options for children, denying them equal learning opportunities. Particularly in rural areas, schools often have poorly equipped science laboratories. Therefore, it is important to provide resources for well-equipped laboratories in schools. The CABE Committee Report on Universalization of Secondary Education (USE) in 2005 set norms for physical infrastructure, including one laboratory each for physics, chemistry, and biology in secondary schools. Additionally, a sub-group on Secondary and Vocational Education for the XI Five Year Plan emphasized the need for laboratories and workshops to promote an experimental culture while reducing the importance of external examinations. The Rashtriya Madhyamik Shiksha Abhiyan (RMSA), launched in 2009 by the Government of India, includes provisions for integrated laboratories in secondary schools and for science equipment, science kits, and science exhibitions to popularize and strengthen science education. The current National Education Policy (NEP) 2020 aims to provide a multidisciplinary and interdisciplinary liberal education to individual learners. The recent rise in epidemics and pandemics necessitates that stakeholders be ready with alternative modes of quality education. It is essential to leverage the advantages of technology while acknowledging its potential risks and dangers, ensuring that online and digital education adequately addresses concerns of equity.

**Laboratory-Scenario at a Glance**

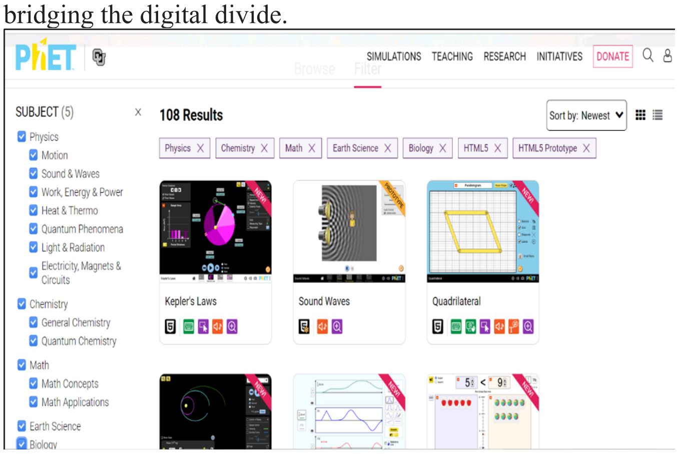
Performing science experiments at various stages of schooling requires establishing laboratories in schools that adhere to safety standards, functional instruments, proper apparatus, and in-date chemicals. However, in the absence of laboratories, vacant positions for science teachers and laboratory staff, and an unfavorable atmosphere, teachers tend to focus more on the theoretical aspects of science. A lack of awareness about the access, use, and importance of science laboratories for the teaching-learning process also significantly contributes to a decreasing scientific attitude and temperament among students. To overcome these challenges, mobile laboratories can be a boon for learners. Atal Tinkering Labs were also launched in several schools. However, without mentoring support, students often copy projects from the internet, and many teachers, being clueless or having less exposure and awareness about technological means, mistakenly believe their students have created something new. Economically, 58% of schools in the country do not have the requisite laboratories. The Unified District Information System on Education (UDISE) and the National Institute of Educational Planning and Administration (NIEPA) revealed in a survey report that the situation of laboratories in several states is much worse than the national average indicates.

Verma (2014) reveals that in the Indian state of Karnataka, only 6% of schools have fully equipped labs for senior students, while in Andhra Pradesh it is only 13%. In Assam, only 4% of schools have labs, and in West Bengal, only 6% of schools have laboratories. Smaller states and union territories like Delhi, Puducherry, Chandigarh, Goa, and even Manipur have a relatively higher proportion of schools with labs for senior students. The National Achievement Survey (2017) also reports that science education in Indian schools is in a poor state, mentioning a school in Daria Village, Chandigarh, that conducts science practicals and music classes in the same room.

**Physics Education Technology (PhET)**

Digital technologies can support necessary educational innovations and act as catalysts for change in educational patterns. Rahayu and Sartika (2020) reveal that interactive simulations significantly affect the motivation and understanding of natural science concepts. Presently, 'PhET' (Physics Education Technology) provides useful simulations accessible both online and offline, through computer and Android-based devices. These simulations cater to Elementary to Higher Secondary levels with content aligned to lab-dependent subjects such as Physics, Biology, and Chemistry. PhET works as a substitute for human inputs that are rarely available in physical format, involving interactive processes through animations and videos that visualize results side-by-side on the same screen. PhET simulations enhance education by expanding on traditional lessons and motivating students to actively participate in science, achieving desired learning outcomes. Since 2002, PhET has delivered more than 806 million simulations, including those in Physics, Chemistry, and Biology. PhET offers multi-dimensional compatibilities (HTML5, Java via CheerpJ, Java, and Flash) and accessibility features (alternative inputs, interactive descriptions, sound and sonification, and zoom and magnification) for its learners.

Hasyim et al. (2020) investigated that learning science using an Android-based PhET Simulation can improve the critical thinking skills of junior high school students. With these simulations, students achieve diverse learning objectives, outcomes, and assessments. Sarwoto et al. (2020) found significant improvement in learning outcomes as a result of online science study through a scientific approach using PhET simulation media. This is based on the premise that lab experiments can be taught over the internet in a cost-effective and efficient manner. These simulations help students compete with their better-equipped counterparts and are a step towards bridging the digital divide.




*(Source:https://phet.colorado.edu/en/simulations/filter?subjects=physics,chemistry,math,earth-science,biology&type=html,prototype, Retrieved on 10.2023)*

**Figure1: PhET online simulation page for different subjects**

## LITERATURE REVIEW

Some important studies were reviewed during the 2020-23 as shown in the table-1. These studies were based on different research methods and conclude that learning Science by using PhET Simulation can improve the critical thinking, lab skills among learners and affects the motivation and understanding of the concept of natural science both online and offline mode such as faiz et al. (2020) studied the use of Android-based PhET Simulation to improve students' critical thinking skills during the COVID-19 pandemic and found that it can enhance junior high school students' critical thinking. Rahayu and Sartika (2020) examined the impact of PhET interactive simulations on students' learning motivation and understanding of science concepts, finding positive effects. Kizito et al. (2020) compared the effectiveness of PhET simulations and YouTube videos for learning optics in Rwandan secondary schools, revealing both to be equally effective. Sarwoto et al. (2020) developed an online science teaching instrument using PhET simulation, which significantly improved elementary students' learning outcomes. Taibu et al. (2021) found that PhET simulations improved scientific skills and attitudes in community college students, with positive experiences reported. Sari et al. (2021) observed that PhET simulations increased students' interest in physics during the COVID-19 pandemic. Verawati et al. (2022) reported that PhET virtual simulations in biology classes positively impacted learning outcomes. Nizar et al. (2022) found that PhET simulations with a well-designed module and teaching plan improved students' achievement in physics. Umiliya et al. (2023) showed that PhET simulations with an inquiry learning model facilitated independent learning and virtual experiments, addressing limited school facilities. Wirda et al. (2023) demonstrated that PhET simulations can replace real laboratories in physics learning, improving academic achievement, student performance, thinking skills, and interaction.

Based on the reviewed studies, the following keywords were found to do more work in relation with PhET simulation:

- Impact on Critical Thinking Skills
- Motivation and Concept Understanding
- Comparative Effectiveness of Learning Tools
- Learning Outcomes Improvement
- Development of Scientific Skills and Attitudes
- Interest in Subject Matter
- Virtual Simulations in Different Subjects
- Module and Teaching Plan Design
- Facilitation of Independent Learning
- Replacement of Real Laboratories

Why PhET differ from other educational tools?

PhET simulation learning, using a discovery learning model, can improve students' understanding of concepts (Anisha et al., 2022). PhET simulations provide learners with multi-dimensional learning styles and an open-ended learning environment. They can repeat any experiment anytime and anywhere without fear of damaging costly equipment or risking exposing students to hazardous chemicals. Problems such as cleaning apparatus, rusting on instruments, and spoilage of chemicals are also resolved, and chemical reactions can be performed regardless of temperature and sunlight issues, yielding errorless results. Learners themselves can assess their learning performance using online learning-enabled assessments.

**Features of PhET**

**Text:** Simulations present data on-screen and convey concepts through associated visuals. Text within the augmented reality app provides relevant information accessible by clicking the mouse or touching the designated area on the screen.

**Graphics:** There are four primary applications of graphics in simulations: conveying basic information, using analogies or methods, organizing content, and providing cues within the augmented reality application suite. Graphics help attract attention, facilitate communication, and aid in memory retention by directing students' focus.

**Audio:** PhET integrates audio to supplement visual content from textbooks, enhancing navigation through the field of information. Combining visual presentation with audio explanations delivers information in an easily comprehensible format.

**Video:** Simulation videos depict real-world motion, including images, laboratory experiments, reactions, and interactive activities.

**Animation:** Animations in PhET simulations offer multiple perspectives, enhancing the visual impact of multimedia presentations. Interactive effects allow users to engage with animations by using mouse/touchscreen gestures or adjusting smartphone angles.

**Interactivity:** Integrating audio, video, text, animation, and graphics in simulations provides hands-on practice that engages learners and promotes deeper understanding of course content. This approach strengthens problem-solving and critical thinking skills.

**Challenges and Games:** Traditional teaching often struggles to engage learners effectively. Simulations, however, are designed to stimulate curiosity and encourage learners to embrace challenges, fostering a spirit of exploration and motivation.

**Access and use of PhET**

"PhET can be used as an open-access source; individuals can register free of cost at the official website (https://phet.colorado.edu/) and log in to their accounts. Proper introductions and step-by-step procedures in various languages are provided for physics, biology, and chemistry experiments. Through the 'Simulation' tab, experiments can be performed step-by-step. Animations help learners understand how to conduct experiments, providing hints and tooltips that include measurements and equipment operation. The video tab allows users to view how to perform simulation-based experiments interactively. PhET simulations can be utilized before, during, and after conducting experiments in a physical laboratory. The Simulation tab offers tips for using PhET in physics, biology,

and chemistry. The Teaching tab facilitates browsing and sharing activities and virtual workshops. The Accessibility tab provides information about accessible simulations, research, design, and technical implementations.

Worksheets and portfolios provide information about authors, including email addresses, enabling teachers to communicate for clarification at any stage. The Translation tab in PhET supports seven languages, including Hindi, Telugu, Tamil, Marathi, Kannada, Gujarati, and Oriya."

**Important parameters of PhET for Science education**

**Cognitive Effort:** Under this parameter learner discover learning in different dimensions; see the unseen and juxtaposing information related to their textbooks. Psychological feature effort is concerning however, the magnitude of psychological feature effort required to unravel a task may have an effect on learning.

**Motivation:** Students' increase involvement in learning science, and develop positive attitude towards science through motivation, shows greater progression. Motivated students put additional effort to troublesome tasks and in turn improve their skills. Once students their skills then make an extra effort to learn difficult tasks and achieve higher learning.

**Situated learning:** simulations enhance the way to present the information and knowledge and the sense of presence, immersion, immediacy, cooperation, interaction and location. The learning that happens associate with authentic context, increases commitment, motivation and cooperation amongst learners

**Inquiry based learning:** Interaction and textbook-based initiatives that area unit's highlight is dynamical teaching and shifted from deductive to inquiry-based. Inquiry-based teaching in science promotes students' curiosity and interest in science. Additionally, it may also facilitate to develop students' social skills and their ability to solve open-ended problems. Students need to solve the basic level, conduct independent learning and work in groups to create their own affiliation, creation, and organization for future application in similar issues.

**PHET FOR CHEMISTRY**

PhET chemistry simulations cover topics ranging from acid-base solutions to waves on a string. Through interactive representations, these simulations enable students to explore strong and weak acids, use laboratory tools on mobile and computer platforms, understand characteristics and properties of solutions, determine conductivity of electrodes in solutions, and investigate the effects of light and various phenomena. Step-by-step multiple representations of individual activities are possible. Learners can engage with simulations in a dynamic system that is streamlined with each experiment and activity. The platform also includes a list of available chemistry simulations, descriptions for each simulation, and a sample pedagogical process for accessing and using them step-by-step, with updated supporting information. Figures 2A, 2B, 2C, and 2D highlight a chemistry simulation example illustrating the process of examining concentration in a solution."

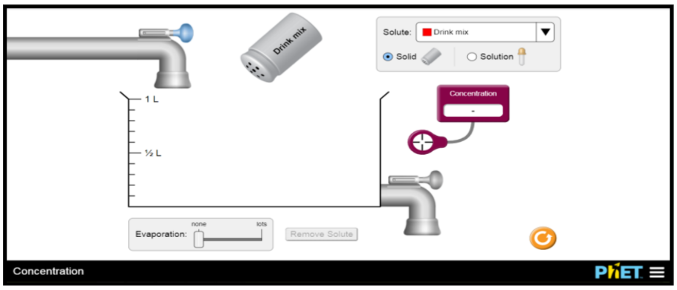



**Figure2A: Concentration of solid Simulation**

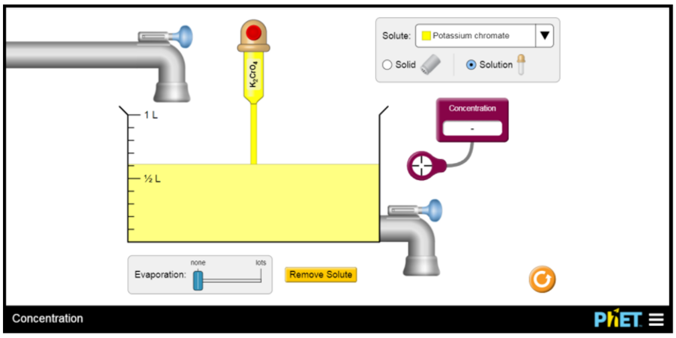



**Figure2B: Concentration of solute**

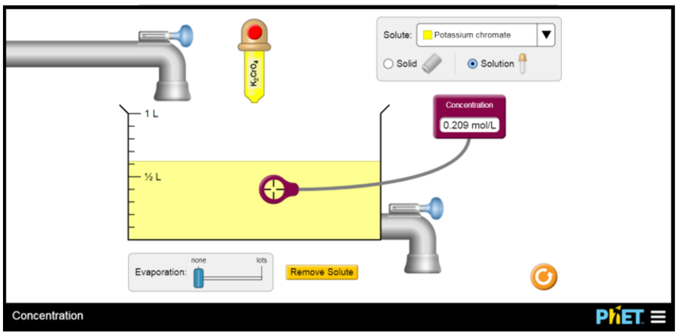



**Figure2C: Examination of concentration**

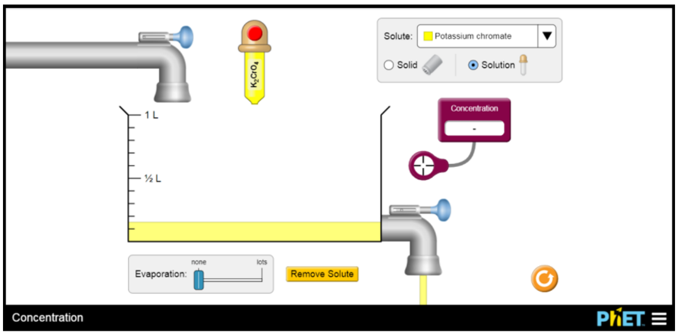



**Figure2D: Removal of solute at outlet**

Further, Teacher can administer test to assess the Learning Outcomes on the above experiment such as

What will happen to the concentration when water is added to tripe in solution volume?

1. Concentration will increase
2. Concentration will decrease
3. No change in Concentration
4. Depends upon solute ratio

**PhET FOR PHYSICS**

PhET physics simulations provide a wide variety of activities, virtual simulation kits, and experiments. Around 106 simulations are available for performing physics-related activities, ranging from alpha decay and atomic interactions to band structure. These simulations cover topics from conceptual knowledge to advanced subjects such as semiconductors, radioactivity, and the greenhouse effect. The physics simulations are organized into seven categories: Motion, Work, Energy & Power, Sound and Waves, Heat & Thermodynamics, and Quantum Phenomena. These simulations allow teachers to share teaching materials with learners, increasing engagement and leading to better learning outcomes. Each simulation can be accessed with a simple click-and-drag option using a mouse or the touch panel of an Android phone. They also provide graphical, animated, and audio feedback with each movement within the simulation. As shown in figures 3A, 3B, 3C, and 3D, a physics simulation example illustrates the calculation of resistance in a wire with variations in resistivity, length, and area of the wire independently.

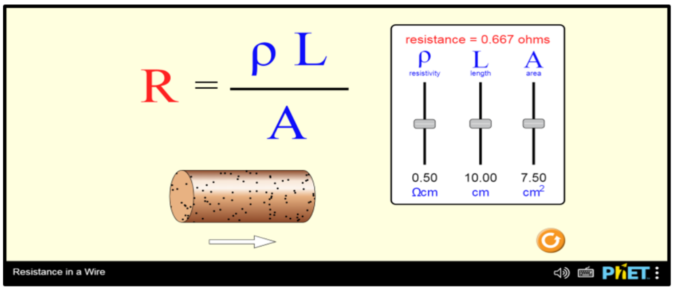



**Figure3A: Resistance in a Wire**

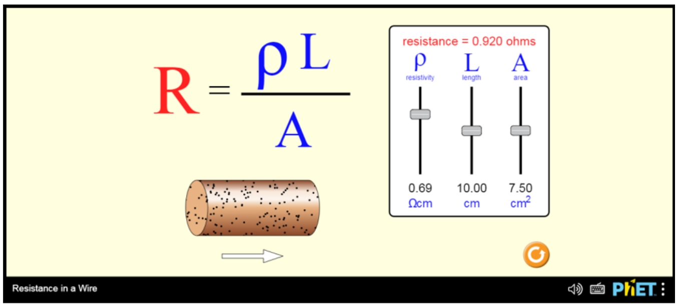



**Figure 3B: Variation of Resistivity value**

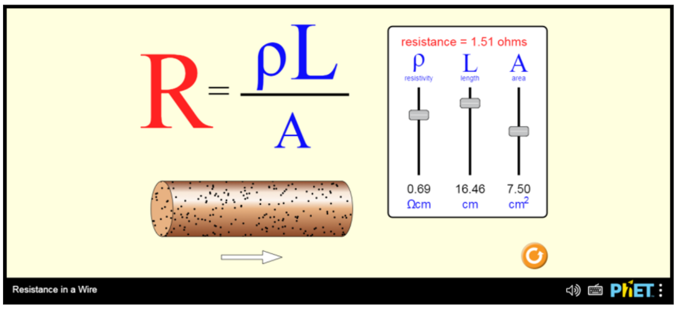



**Figure 3C: Variation in the Length of wire**

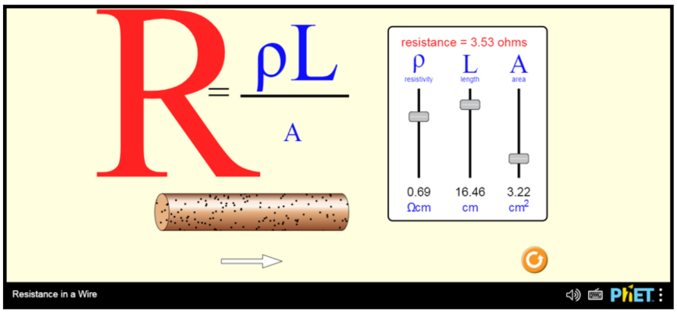



**Figure 3D: Variation in the Area of wire**

Further, Teacher can administer test to assess the Learning Outcomes on the above activities such as:

What will change in the value of Resistance, if resistivity and area of the wire remain constant and increase the Length of a sample wire?

1. Resistance value will increase
2. Resistance value will decrease
3. Resistance value remain constant
4. None of the above

**PhET FOR BIOLOGY**

PhET simulations encourage green science through digitally enriched simulations and visual models that help learners understand, interpret, and analyse, inherently promoting inquiry. They are useful for both teachers and students to perform experiments and activities in an exploratory way. Learners at different stages can interactively observe the simulation process with various available input and output components. Under the biology tab, 19 simulations are available to accomplish tasks such as colour vision, eating and exercise, stretching DNA, gene expression essentials, and more.

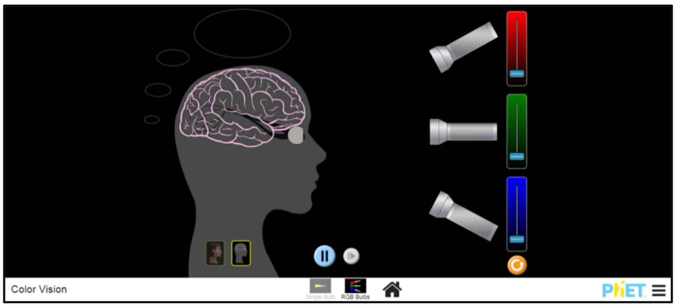



Figure 4A: Colour vision

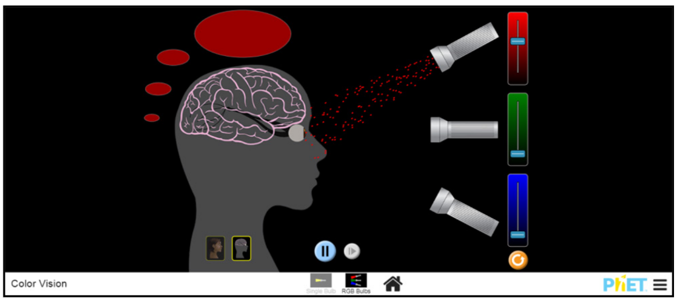



Figure 4B: Colour vision with Red, colour

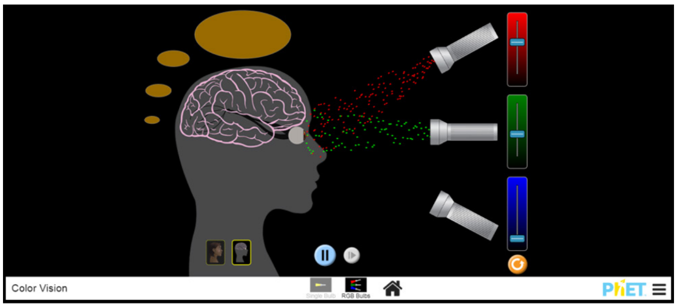



**Figure 4C: Colour vision with Red and Green colour**

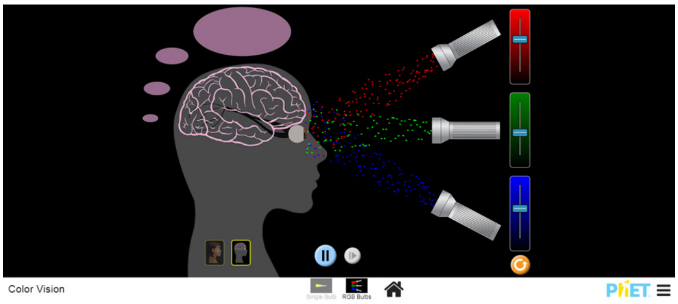



**Figure 4D: Colour vision with Red, Green colour and Blue Colour**

Further, Teacher can administer test to assess the Learning Outcomes on the above activities such as

**Which one of the phenomenon of light responsible for the working of the human eye?**

1. Reflection
2. Refraction
3. Power of accommodation
4. Persistence of vision

## CONCLUSION

Information, communication, and technology play important roles in assisting the teaching-learning process. During the COVID-19 pandemic and the Omicron variant, ICT was incorporated into the learning of science, engaging learners and giving them first-hand experience. PhET simulations are effectively used in many countries; they not only provide a simulated experience but also reinforce theoretical concepts. Many studies have been conducted on PhET simulations based on physics, biology, and chemistry. Most of these studies demonstrate positive effectiveness and the successful use of PhET in science subjects, particularly physics. Therefore, learning science in terms of inclusive, immersive, and equitable education requires these simulations. They engage learners, enable them to understand difficult concepts through simulations, make science learning interesting, and foster a scientific temperament among learners.

### Educational Implications

- Researchers can explore how PhET simulations specifically improve critical thinking skills and which aspects of the simulations are most effective.
- Studies can be conducted to identify the elements of PhET simulations that contribute most to increasing motivation and concept understanding.
- Research can focus on the instructional strategies combined with PhET simulations that yield the best learning outcomes and how these strategies impact different grade levels.
- Impact studies can determine which specific scientific skills are most improved by PhET simulations and how these simulations influence students' attitudes toward science.
- E-modules can be developed for effective teaching using PhET simulations, and research can explore how these can be standardized across different educational contexts.
- Research can investigate how PhET simulations support independent learning and identify best practices for integrating inquiry-based learning with PhET simulations.
- Explorative studies can examine the extent to which virtual simulations (PhET) can replace traditional laboratories.

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